I. Introduction

To effectively manage conserved biological preserve lands, a land manager must map important biogeographic features such as vegetation structure and landform change over time and space, e.g., urban growth patterns and habitat disturbance. This type of mapping/analysis is traditionally done with frequent *in situ* field visitations covering limited spatial and temporal extents. However, for San Diego County's Multiple Species Conservation Program (MSCP) projected 101,000 acres of preserve in the initial sub area plan, the staff and time requirements, to perform comprehensive field visits is considered to be logistically impractical and economically unfeasible. An alternative approach to conducting large-scale landscape monitoring and change analysis is the use of remote sensing. With this approach a researcher can remotely detect and map surface variability temporally, spatially, and spectrally through the use of airplane or satellite based sensors.

In this circumstance, satellite and airborne multi-spectral digital imaging techniques have proven useful (Singh 1989) for detecting and monitoring landscape variability with image to image digital number comparisons which among the photogrammetric and remote sensing professional community is referred to as "change detection" (Lambin and Strahler 1994).

Change detection involves the use of multi-temporal images, i.e., data from the same location and at least two different time periods, to discriminate areas of landscape change over time. This comparative process has several considerations when dealing with the desired resolution of the data.

Ideally, remotely sensed imagery used in a change detection process will be acquired at a constant *temporal resolution*, i.e., anniversary dates, while having common ground resolution elements (GRE), or *spatial resolution*. Furthermore, an assumption of digital change detection is that a difference exists in the spectral response of a pixel between two dates if the biophysical materials have changed. This is referred to as *spectral resolution*. Finally, the data storage and collection format is considered in *radiometric resolution*,[1] e.g., the imagery collected was based on an 8-bit data model on both dates (Hall et al. 1991, Jensen 1996). Scientifically robust change detection methods require that these resolution factors be comparable between image dates. This was achieved in the research conducted on the study areas of Lusardi Creek and 4S Ranch in San Diego County, California (figures 1-1.1, 1-1.2, and 1-1.3).

This report describes the change detection techniques and remote sensing research conducted in these areas, and briefly describes the vegetation survey and fieldwork performed. Beyond the requirements of the research design, an additional remote sensing platform: satellite-based Landsat Thematic Mapper (TM) was compared and contrasted to the original research platform: airplane based Airborne Digital Acquisition and Registration (ADAR) in our study areas.

II. Study Areas, Preserve Areas, and Field Methods

In situ information is essential knowledge for any remote sensing project. To this extent, field visits were conducted by county staff before, during, and after the imagery was captured in 2000 and 2001. Extensive natural history/botanical survey work was performed in the spring of 2001. The preserve areas of Lusardi Creek and 4S Ranch are proximal to each other on an east to west axis. These areas are entirely contained in the remote sensing study areas (figure 1-1.2 and figure 1-1.3). The spatial extent of remote sensing analysis areas are larger than the preserve areas so as to avoid the potential of edge effects that could result in false change detection. Subsequently, information derived from these study areas describes features both inside and outside of the official MSCP preserve system.

These preserve sites are located in the middle to western portions of the County of San Diego in an area where only recently (within the last 10 years) mass land development has occurred. The initial field surveys were performed to record the locations of rare plants. Later field visits were conducted to verify or field check areas in the preserves and surrounding areas for changes in remotely sensed imagery flown in the years of 1992 to 1999 and 2000 to 2001.

The Lusardi Creek preserve area (figure 2-1) can be physically described as a roughly rectangular preserve area east of Solana Beach. Black Mountain Ranch borders it to the south, Rancho Santa Fe and Fairbanks Ranch to the west, and a rural estate development along Artesian Road to the north. Lusardi Creek flows from near the southeastern boundary west through the southwestern portion of the parcel. Lusardi Creek is dominated by three relatively level mesas with gentle or steep slopes falling toward Lusardi Creek. The eastern most portion of the preserve area is dominated by a rugged series of slopes bordering a south-flowing canyon. The elevation of Lusardi Creek varies from about 20 to 113 meters (65 to 370 feet). Lusardi Creek is dominated by riparian vegetation. The two western most mesas are dominated by chamise chaparral. The easternmost mesa is dominated by open grassy coastal sage scrub with weak mima mounds.

4S Ranch is a relatively narrow preserve area (figure 2-2) with an east to west axis following upper Lusardi Creek. The terrain is generally fairly gentle with the highest slopes in the east and a central lake. The elevation varies from 110 to 308 meters (360 to 1,010 feet). The eastern hills are dominated by coastal sage scrub that has recently burned. The central portion is dominated by annual grassland that has been heavily invaded by wild artichoke thistle following a narrow marshy area with a lake. The western portion consists of low hills dominated by coastal sage scrub and a gentle north-facing slope dominated by southern needlegrass grassland.

The field methods implemented included presence surveys for rare plants with counts and population estimates made for specific species. These surveys were conducted throughout the study area from mid March through June with three additional one-day surveys in July and November 2001. Surveys were conducted on the Lusardi Creek preserve area on April 18th, 19th, 24th, 25th, 26th, May 3rd, 10th, 24th, 30th, and June 19th, 2001. Surveys were conducted on the 4S Ranch preserve area on April 26th, May 2nd, May 4th, May 8th, June 19th, June 21st, and July 12th, 2001.

Generally the weather was cool and cloudy in March and April gradually becoming more clear and hot by late May and June. March 26th, however, was an exceptionally hot day for the season. The peak of the bloom on Lusardi Creek occurred in late April while the peak bloom occurred in May for 4S Ranch. By early June most of the rare plants identified were concentrated along watercourses.

Surveys were conducted primarily on foot favoring ridgelines and barrens. Each colony of rare plants located was given a unique identifier code (See “Rover files” Appendix 1). Rare plant sites were delineated generally and/or specifically when possible. Specific point, line, and polygon locations of rare plants were marked with a GPS unit (Trimble Geoexplorer III). Individual GPS points were used to record the location of individual or small groups of rare plants that did not cover an appreciable area. GPS Polygons were used where rare plants formed a well-defined patch or extended group that could be delineated by walking around it. Nested points were occasionally collected where additional species were noted within the larger polygon of another species. Colonies were considered distinct if they were more than 15 meters apart or easily distinguished on field maps (1:6000 scale). The GPS files were downloaded, corrected for GPS error, and imported into an ArcGIS 8.0 geodatabase (figures 2-3 and 2-4) by County of San Diego, Department of Planning and Land Use - MSCP Division staff on a weekly basis.

The approximate abundance of plants per colony (or stand) was recorded by direct count or through estimation if the numbers exceeded 500 to 1,500 individuals. Since this initial field research represents the first presence surveys conducted in these newly created preserve areas, no parametric or quantitative methods were used beyond counts or rough population size estimations. Notes were taken on the ecological features (exposure, aspect, soils, associated species) for each colony (or stand). In species such as western dichondra (*Dichondra occidentalis*), where number is either undeterminable or irrelevant, site coverage was estimated.

Typically, GPS records were not made for wart-stemmed ashy spike moss (*Selaginella cinerascens*). Locations for these species were noted on a field map. Aspect and vegetation information was recorded where possible. In most cases, general site data does not include estimated numbers of individuals for concomitant but not rare plant species.

Representative vouchers were taken for the majority of rare plant species with at least one representative for each area. Vouchers are noted under specific colonies (or stands) (See Notes: Appendix 1). Vouchers will be deposited at the San Diego County Natural History Museum. Finally, County vegetation maps for each of the parcels were reviewed. Modifications to these maps were made in the associated Holland vegetation classes (Appendix 2) where errors, corrections, or minor changes were appropriate. The modified vegetation maps were then digitized and edited into an Arc INFO 8.0 polygon coverage (figures 2-5 and 2-6).

Fifteen species of rare plants were encountered in the preserve areas. Twelve of these species are listed within the California native Plant Society's Inventory of Rare and Endangered Plants of California (See Table 2.1). The sparse-flowered hesperevax (*Hesperevax sparsiflorus*), which is found in the Lusardi Creek area, is considered locally rare. Additionally, the Del Mar manzanita (*Arctostaphylos glandulosa* ssp. *crassifolia*), which is also present in limited numbers, is currently listed as endangered under the federal or State Endangered Species Acts. Rare species and their rank are summarized in Table 2.1.

Table 2.1 – Rare Plant Flora of Lusardi Creek and 4S Ranch Preserve Areas

Latin Binomial	Common Name	Rank
Adolphia californica	Califronia Adolphia	CNPS 2
Arctostaphylos glandulosa ssp. Crassifolia	Del Mar Manzanita	Fed E, CNPS 1B
Comarostaphylos diversifolia ssp. Diversifolia	Summer Holly	CNPS 1B
Convolvulus simulans	Small-flowering Morning Glory	CNPS 4
Dichondra occidentalis	Western Dichondra	CNPS 4
Dudleya variegata	Varigated Dudleya	CNPS 1B
Ferrocactus viridescens	San Diego Barrel Cactus	CNPS 2
Harpagonella palmeri	Palmer's Grappling Hook	CNPS 4
Hesperevax sparsiflorus	Sparse-flowered Evax	Locally rare
Iva hayesiana	San Diego Marsh-elder	CNPS 2
Juncus acutus ssp. Leopoldii	Spiny Rush	CNPS 4
Lepidium virginicum var. robinsonii	Robinson's Peppergrass	CNPS 1B
Microseris douglasii var. platycarpha	Small-flowering Microseris	CNPS 4
Pentachaeta aurea	Golden-rayed Pentachaeta	CNPS 4
Selaginella cinerascens	Ashy Spike Moss	Locally rare

Fed E = Species designated as endangered under the federal Endangered Species Act
CNPS 1B = Plants Rare, Threatened or Endangered in California and elsewhere
CNPS 2 = Plants Rare, Threatened or Endangered in California but more common elsewhere.
CNPS 4 = Plants of limited distribution.

III. Change Detection Techniques Using Landsat Thematic Mapper Data

The images shown below (figure 3-1) are portions of two Landsat TM digital images recorded on August 1992 and August 1999 from an approximate altitude of 700 km. Landsat TM images have an approximate spatial resolution of 30 meters. The images shown cover the Lusardi Creek and 4S Ranch area of San Diego County. The images were geometrically registered to each other, meaning that the same pixel within both images represents the same location on the ground. They were also radiometrically calibrated using pseudo-invariant feature subtraction (Hall et al. 1991, Schott et al 1988).

Figure 3-1 Landsat Imagery of Lusardi Creek and 4S Ranch bands 3,2,1

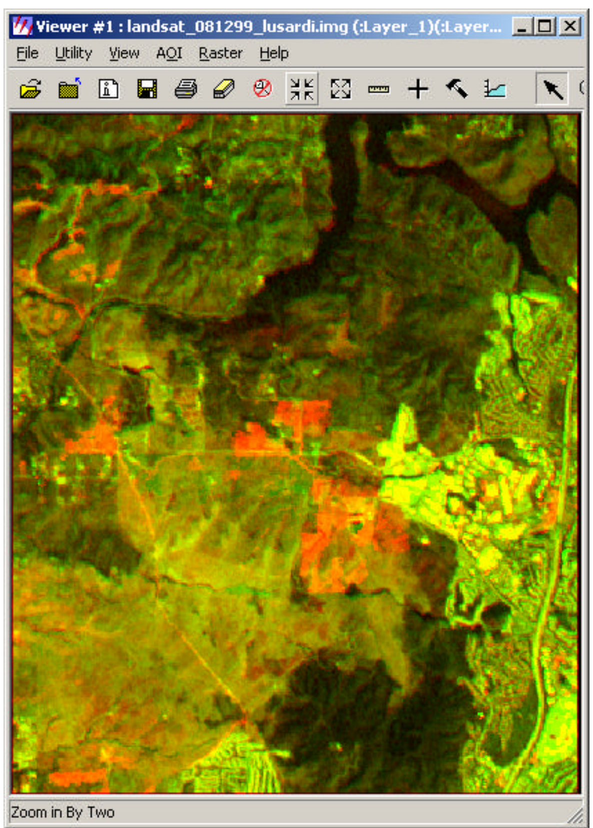
1992

1999

Three change detection methods were performed and their outputs visually compared. The multitemporal image pair was used as input into the change-detection procedures to generate digital change images. The digital data were processed using Erdas IMAGINE 8.5 digital image processing software.

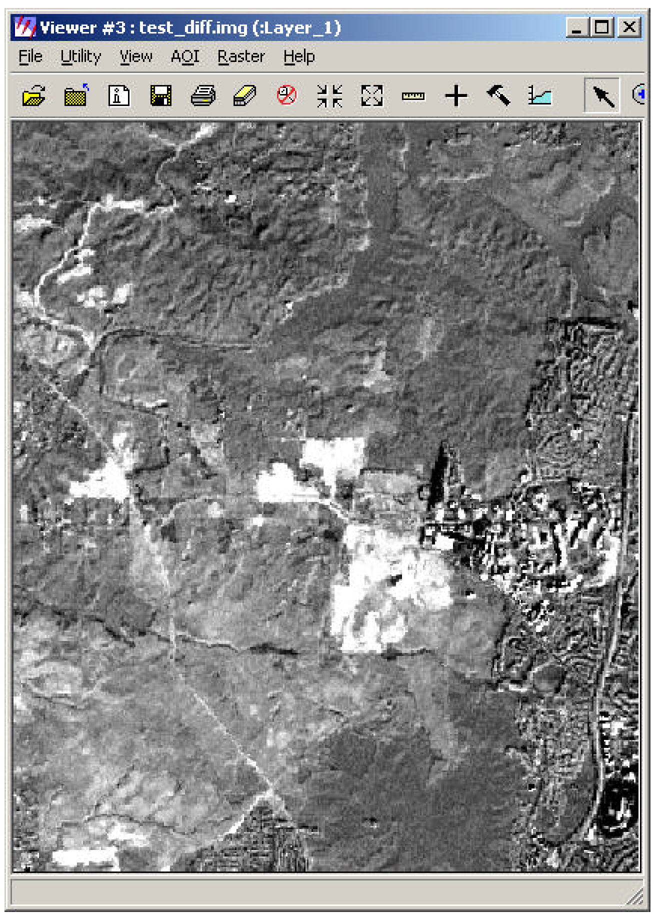
It is possible to visually identify change in the imagery, for up to three image dates, by inserting individual bands of data into specific write function memory banks (red, green, blue) in ERDAS IMAGINE (Jensen, 1996). The result of inserting band 1 from the 1992 image in the green color gun, band 1 in the 1999 image in the red color gun, and no image in the blue color gun can be seen in figure 2. All areas that did not change are depicted in yellow. This method builds off of *additive color theory* where equal intensities of green and red result in yellow. The graphic depicts new urban development and vegetation clearing in red. Potential vegetation re-growth and non-native landscaping in the urbanized areas are depicted in green.

Figure 3-2 Landsat Multi-date Additive Color Composite



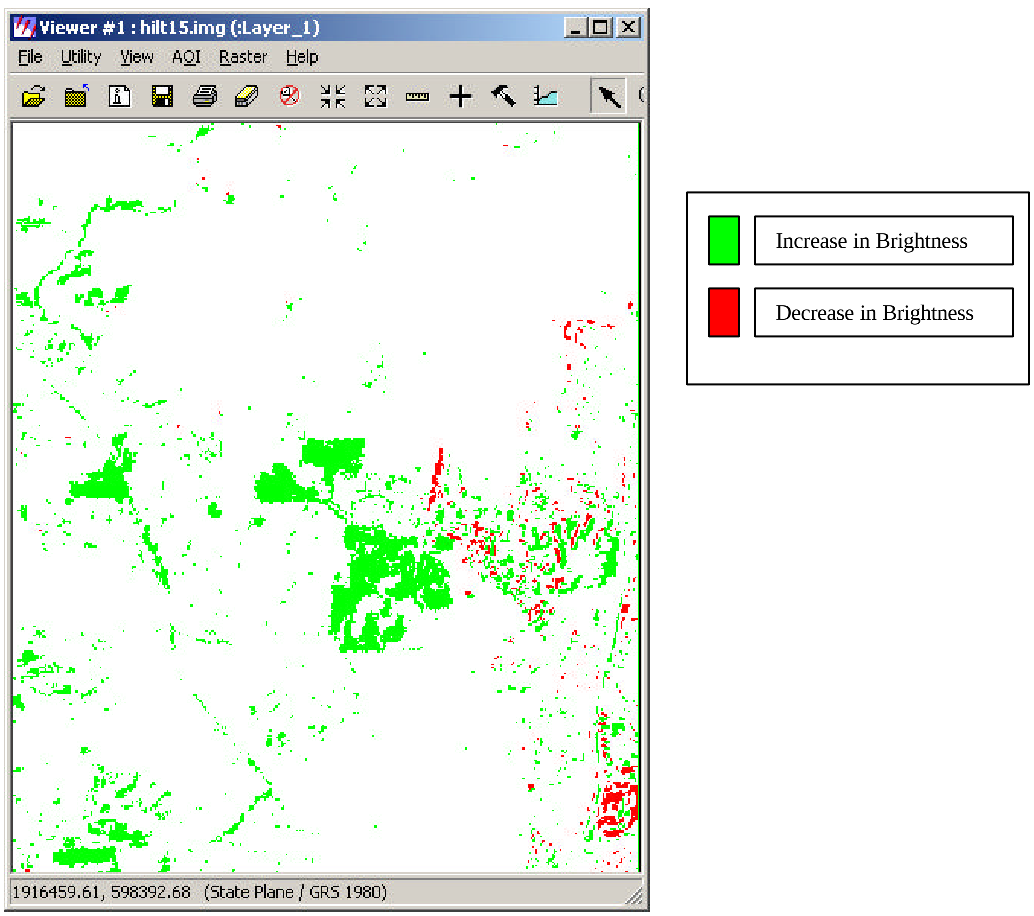
In a different technique, simple identification of the amount of change is possible between two images by image differencing the same band in the two images (Green 1994 in Jensen 1996). Image differencing involves subtracting one date's image from another. The result is positive and negative values in areas of change and zero values in areas of no change (figure 3-3). The change image usually results in a histogram of brightness values (BV) having a Gaussian distribution. The pixels of no BV change are distributed around the mean and pixels of change are found in the tails of the distribution (Price et al 1992 in Jensen 1996). Therefore, "the gray tones of each pixel on a change detection image portray the amount of difference between the original images" (LOGICON 1997). This technique offers no information of the nature of change. Rather, it identifies the areas that may have changed.

Figure 3-3 Landsat Image Differencing Output



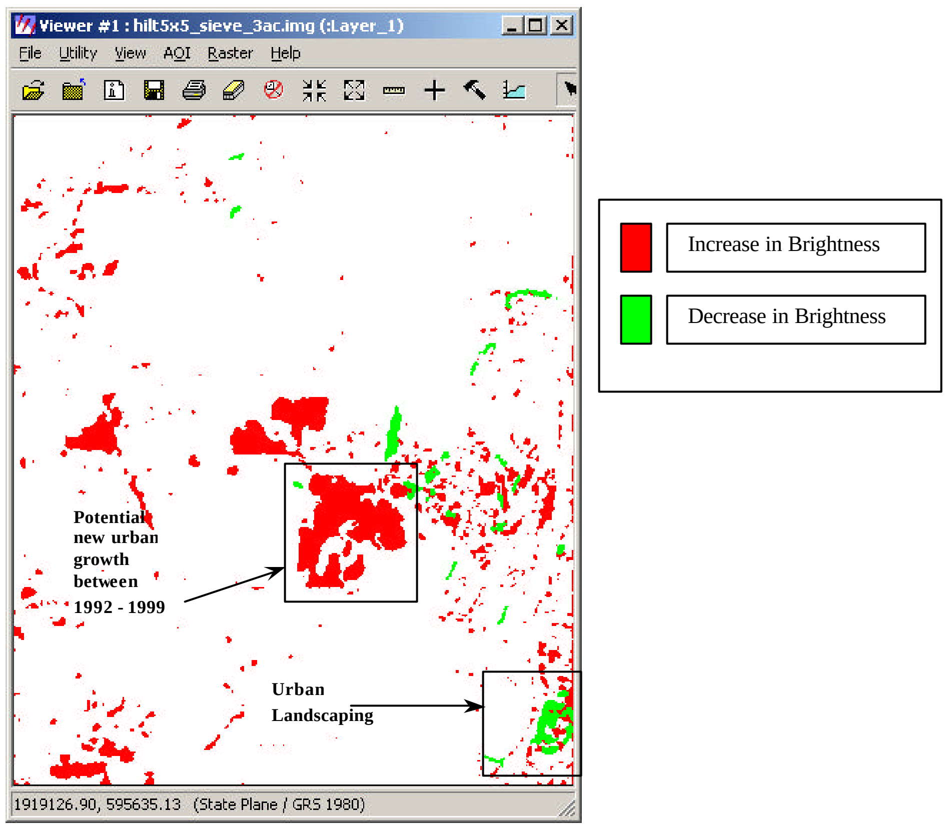
Quantification of potential change is possible using a binary change mask. A threshold boundary between change and no-change is decided upon. Areas of change are recoded to a value of one, and areas of no change are recoded with a value of zero. The graphic below shows the areas of change in red and green (figure 3-4). Green depicts areas that increased in BV and red depicts areas that decreased in BV. A threshold of 10% change[2] was chosen based on comparison with the multi-date composite image discussed above. The binary change mask can then be imported into a GIS and quantification of the potential change can be performed. Of the approximately 22,000 acres in the Lusardi Creek/4S Ranch Landsat study area, roughly 1,680 acres or 8% changed between the two dates using a 10% change-no change threshold.

Figure 3-4 Landsat Binary Change Mask



The second binary change mask is the result of aggregating the continuous areas of change with a minimum unit of 3 acres (Note the colors are reversed from the above graphic, see figure 3-5). This method is useful in creating change hotspots that require field investigation or further interpretation using higher resolution imagery such as that created with the ADAR or IKONOS (5 meter multispectral satellite-based; see www.spaceimaging.com) platforms.

Figure 3-5 Aggregated Landsat Binary Change Mask



Multispectral vegetation indices, such as the normalized difference vegetation index (NDVI), can also be used in this type of research to compare between date differences in the greenness of an area. The graphics below are NDVI images for 1992 and 1999 (figure 3-6).

Figure 3- 6 Landsat NDVI Output

1992

1999

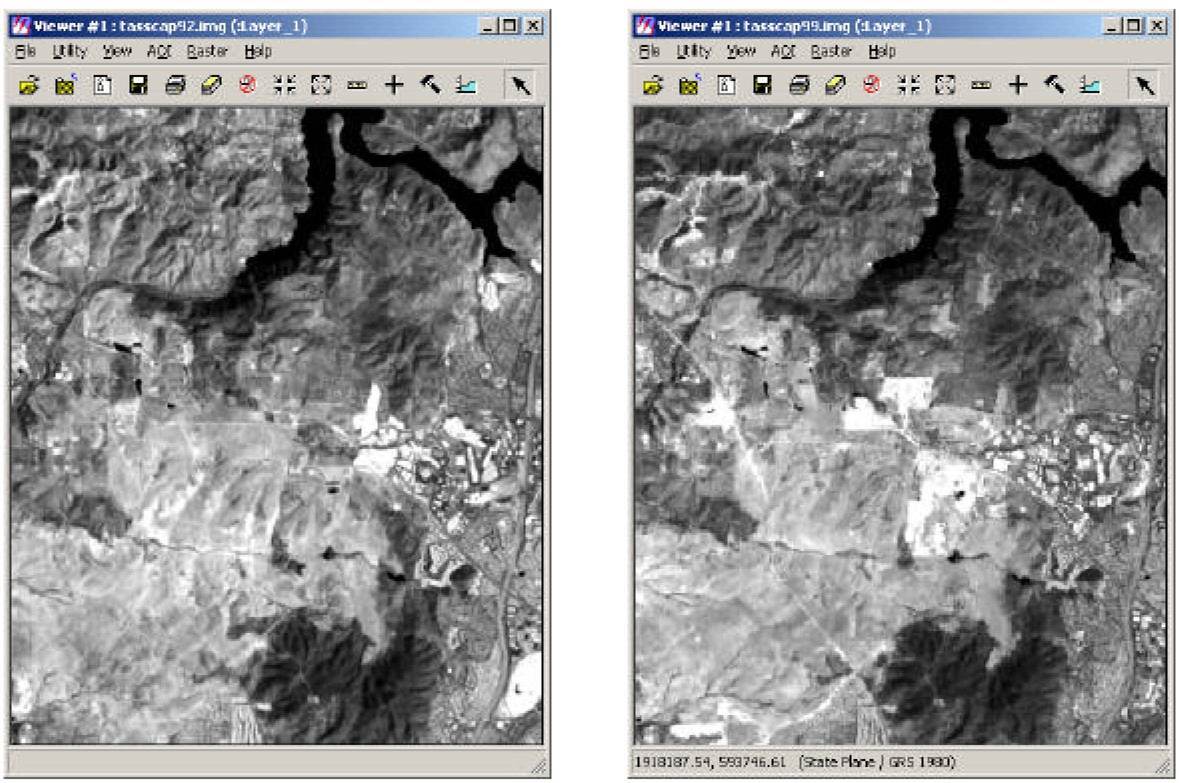
Because NDVI diminishes the spectral influences of the illumination angle, slope, and aspect, it has proven useful in vegetation cover monitoring (Lillesand and Kiefer 1994). The technique can be used to study vegetation phenology of a given community, leaf area index measures, calculating percent bare soil, as well as photosynthetic biomass. The index is typically formulated as follows:

$$NDVI = (NIR - Visible)/(NIR + Visible)$$

With this calculation the range of values extends from 0 to 200, with 0 to 100 generally representing water, soil, and other non-vegetated surfaces and values greater than 100 representing vegetated surfaces. The bright areas in the NDVI images shown here correlate to vegetated surfaces.

In addition to NDVI, other methods exist that aid in detecting change in surface features between dates using remotely sensed imagery. The Tasseled Cap Transformation is one such example where coefficients are applied to the imagery to enhance the greenness, brightness and wetness features in the image scene. The resulting brightness features (i.e. bare soil and concrete) in two image dates can then be differenced to depict potential changes. The following images (figure 3-7) show the bare soil and/or concrete features for the two years and their difference image. The 1999 image clearly indicates an increase in brightness related to bare soil and/or concrete in the study area.

Figure 3-7 Landsat Tasseled Cap Transformation Brightness Output

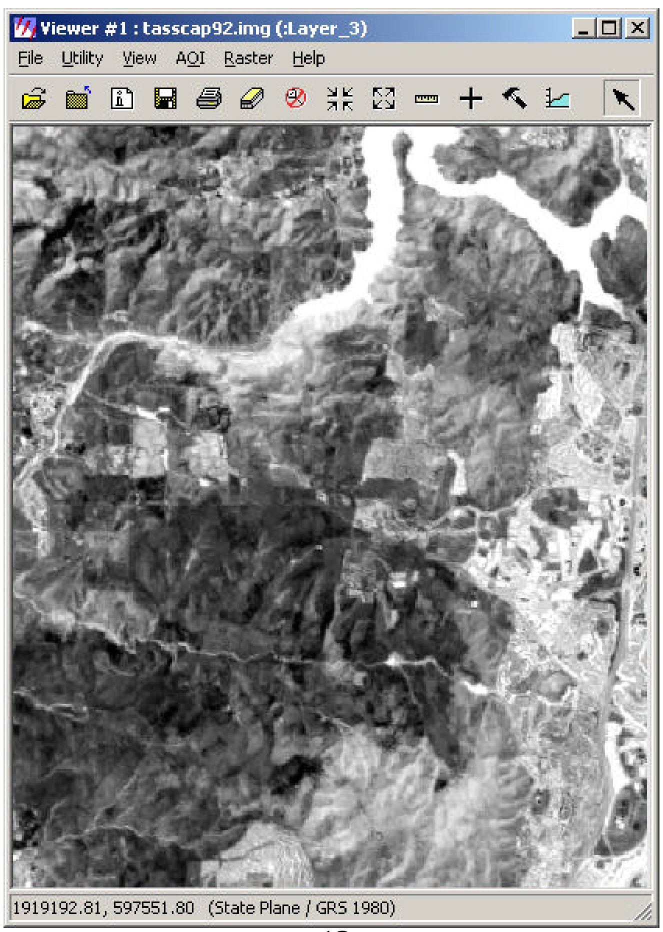


1992 **1999**

The same is true for green and wet features. The image in figure 3-8 depicts the wetness features in the study area in 1992. In this image, the bright areas correspond with the lake and the riparian areas along the creek. Bright gray features in urbanized areas indicate an irrigated landscape, while open water appears bright white (see in upper right, i.e., Lake Hodges).

In addition to spectral indices and band-to-band subtractions, more time-consuming techniques exist that involve classifying the multi-date imagery into individual land cover classes. With these methods, which are beyond the scope of this research, it is possible to difference the classification results. This method is useful because it does give from-to change information. However, the overall accuracy of the change detection is dependant upon the accuracy of each of the individual image classifications. It requires the image analyst have previous knowledge of the study area as well as field data for training the imagery (telling the software which pixel values correspond to which land cover types) and verification of the classification results.

Figure 3-8 Landsat Tasseled Cap Transformation Wetness Output

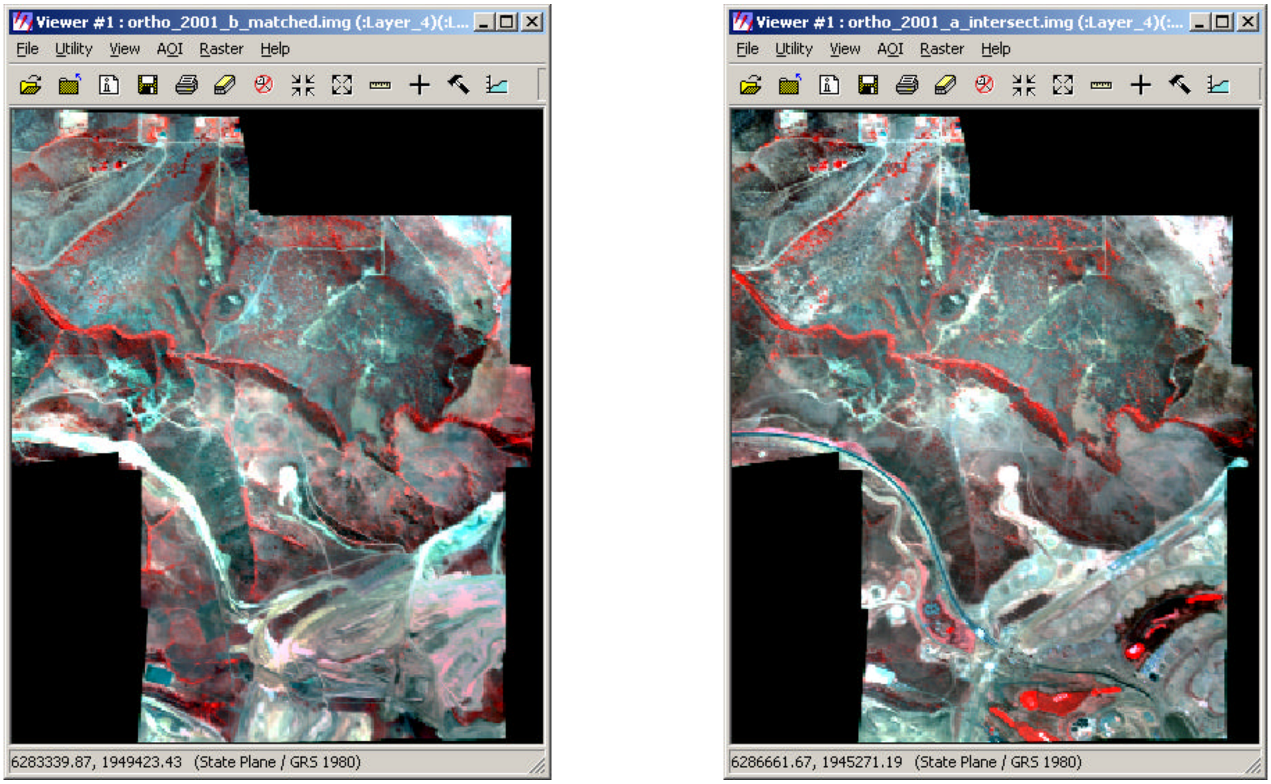


IV. Change Detection Techniques Using ADAR Data

The ADAR System 5500, developed by Positive Systems; Whitefish, Montana, acquires digital photographs in four configurable spectral bands using four different digital cameras. It is typically used in diverse applications including wetlands monitoring, forestry management, precision agriculture, mining, military surveillance and environmental compliance and monitoring. The system is airplane based and can generate 0.5 to 3 meter GRE multi-spectral imagery for a reasonable cost. All ADAR imagery not produced as a synoptic scene requires radiometric correction and mosaicing (Jensen 1994, pg 121; LOGICON Multispectral imagery reference guide 1997, pg 4-1). Mosaicing, which will be discussed in greater detail, usually is monetarily expensive and/or time intensive.

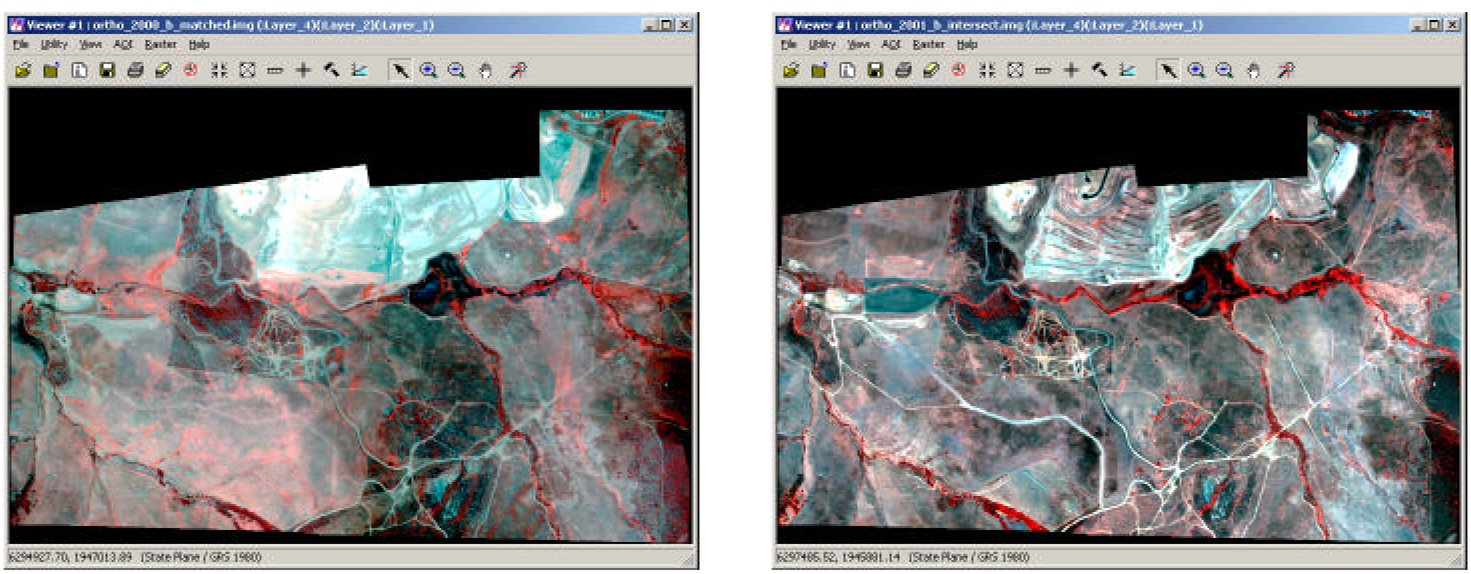
The images below are 2000 and 2001 (figure 4-1.1 and figure 4-1.2) ADAR multi-spectral images for the two study areas, Lusardi Creek and 4S Ranch (figure 1-1.3). The data were collected by the Center for Earth Systems Analysis and Research (*CESAR*) at San Diego State University. The data were pre-processed by Integrated GIS Technologies; San Diego, California prior to input into the change detection algorithms. Pre-processing included ortho-rectification using ERDAS OrthoBASE. Additionally, the images were geometrically registered and radiometrically[1] calibrated (a process not required with the Landsat TM). In these images the 2000 scene has a much brighter histogram than the 2001 image. Consequently the 2000 scene histogram was matched against the 2001 scenes. This technique reduces erroneous change detection results due to different spectral responses that might be caused by seasonal variation and camera calibration differences between the two dates.

Figure 4-1.1 ADAR Lusardi Creek bands 4,3,2



2000 **2001**

Figure 4-1.2 ADAR 4S Ranch bands 4,3,2

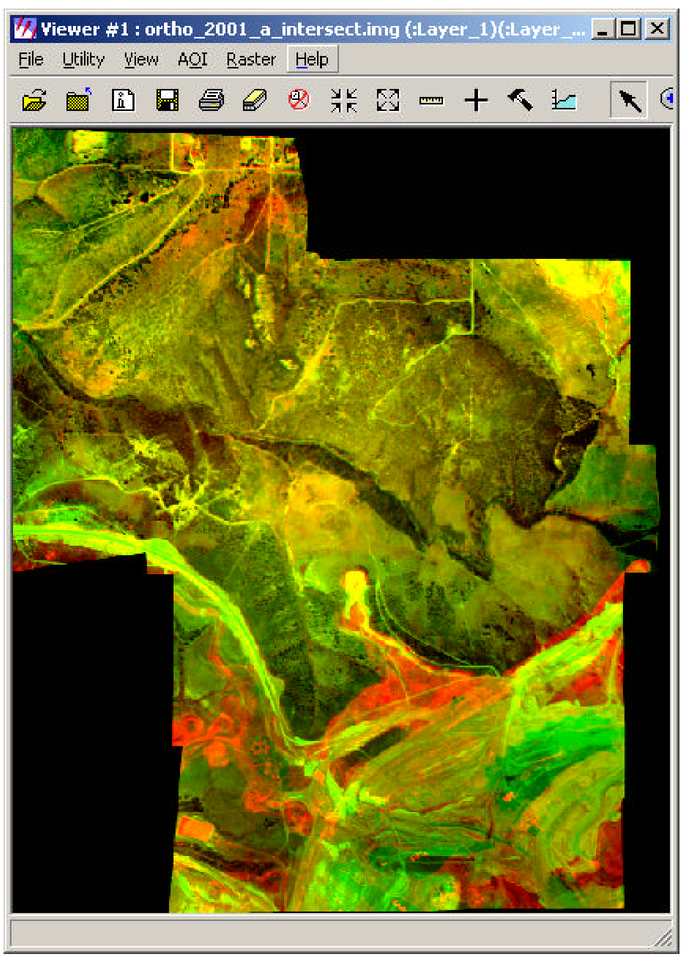


2000 **2001**

Two change detection methods were performed using the ADAR imagery and their outputs visually compared. The multitemporal image pair was used as input into the change-detection procedures to generate digital change images. The data were again processed using ERDAS IMAGINE digital image processing software.

As with the Landsat TM imagery, change was initially assessed using the write function memory insertion technique previously described. The image in figure 4-2 is a result of inserting Band 1 from the 2000 Lusardi Creek image in the green color gun, Band 1 in the 2001 Lusardi Creek image in the red color gun, and no image in the blue color gun. All areas that did not change are depicted in yellow. The graphic depicts potential new urban development and vegetation clearing in red. Potential vegetation re-growth and landscaping in the urbanized areas are depicted in green.

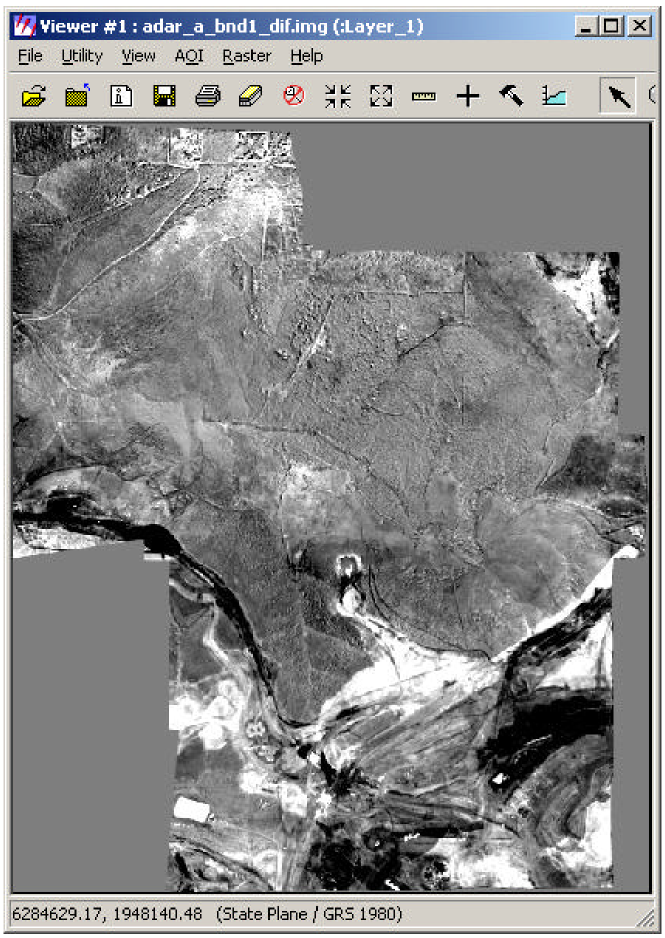
Figure 4-2 ADAR Multi-date Additive Color Composite



The change showed in figure 4-2 was verified through field visits. The red in the above image corresponds to new grading that occurred. The green in the lower right corresponds to landscaping of a residential area and new golf course. The red in the upper left, however, corresponds to a change in the phonological state of non-native grasses (*Avena fatua*) that exist in that area.

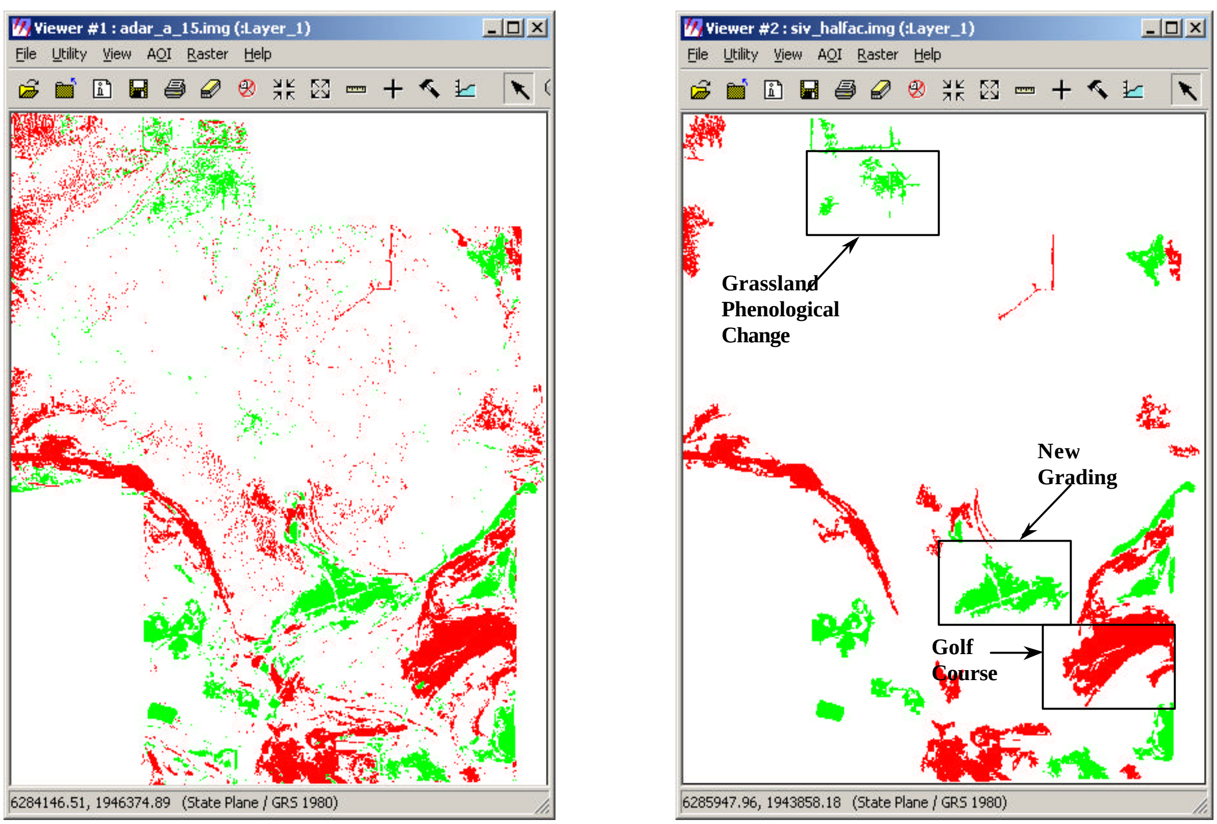
Band-to-band image differencing of Band 1 of the two years yielded change hotspot areas similar to that of the write function memory insertion above. In figure 4-3 the image of Lusardi Creek, change is seen in white and black while no change is in gray. In this example, change due to vegetation removal and phenological difference is not discernible without field checking.

Figure 4-3 ADAR Image Differencing Output



As with the Landsat example, quantification of potential change is possible using a binary change mask. A threshold boundary between change and no-change was decided upon. Areas of change were recoded to a value of one and no change is recoded to a value of zero. The first graphic below shows the areas of change in red and green. Green depicts areas that increased in BV and red depicts areas that decreased in BV. A threshold of 15%[2] change was chosen based on comparison with the multi-date composite image discussed above. The binary change mask is then imported into a GIS for quantification. Of the approximately 1,400 acres in the Lusardi Creek ADAR scene, approximately 186 acres or 13.23% changed between the two dates using a 15% change-no change threshold. The second binary change mask (figure 4-4) is the result of aggregating the continuous areas of change with a minimum unit of a ½ acre. This reduces some of the "noise" in the change-no change mask that might be caused by extraneous factors such as misregistration (Townshend et al. 1992). With the ½ acre minimum mapping unit, change is calculated at 123 acres or approximately 9% of the total 1400 acres in the ADAR scene.

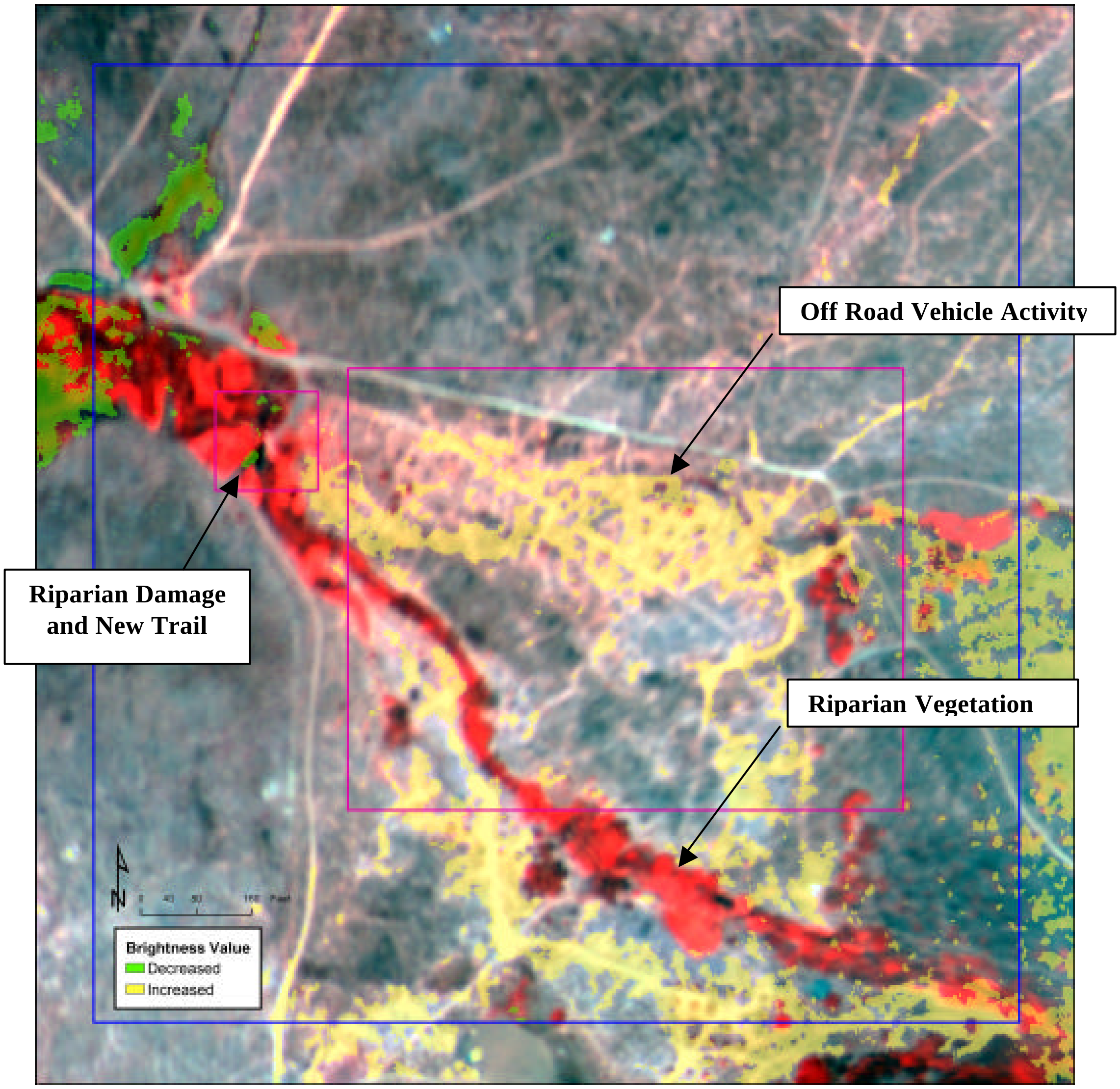
Figure 4-4 ADAR Raw and Aggregated Change Masks



The direction of change (i.e. vegetation removal or vegetation regrowth) can be assumed from the above change-no change mask, where green represents an increase in BV or potential vegetation removal and yellow represents a decrease in BV or potential vegetation re-growth. However, it is noted that these assumptions should be made with caution. The image in figure 4-5 is a subset of the 4S-Ranch ADAR scene. In this image, signatures corresponding to a decrease in BV between dates along the riparian corridor could have been erroneously categorized as an increase in vegetation. However, after a field visit to this location, it was determined that the decrease in BV actually corresponded to mud from a new road being cut through the stream channel.

Although BV changes can incorrectly categorized the land use change, this seems to be the exception rather than the rule in ADAR image interpretation. For example figure 4-6 indicates how well the detected (and field checked) changes can be categorize with ADAR.

Figure 4-5 ADAR 4S Ranch 2001 Brightness Change Overlay - Field Check



V. Discussion of Landsat and ADAR Remote Sensing Techniques as Biological Monitoring Utilities

The well tested and relatively inexpensive nature of Landsat imagery makes it an ideal choice for large land use/land change analysis in the MSCP preserve system. In compliance with the approved MSCP, periodic surveys of the preserve system are required to insure non-conforming land uses have not accidentally or surreptitiously occurred, e.g., illegal grading. With limited funds and personnel availability, it appears very prudent to utilize Landsat as a yearly initial assessment technique (See Table 5.1).

Table 5.1 Landsat – ADAR Cost Comparison

	Landsat	ADAR
Image Cost	.04 Cents per square mile per scene*	$150-300 per square mile per flight
Change Detection Image Prep	$120 per scene*	$1021 per square mile
Resolution	30 meter	1 meter
Bands	7	4
Staff time for change detection	4 hrs	4 hrs

* One Landsat scene is 13214 square miles

The results of a regular remote assessment could better direct the time and efforts of field biologist towards future areas of concern or change where the preserve system's sensitive flora and fauna could be threatened.

The rough scale detail of Landsat falls short of the level of detail required to resolve individual groups of sensitive plants or features less then the pixel size (30 m). When a circumstance requires highly detailed multi-spectral information of a site or a specific disturbance, such as a fire, high resolution imagery is a requirement. ADAR imagery can provide this level of detail, however it requires a more time intensive level of pre and post processing to create a usable imagery product. This is a cost benefit decision that must be based upon the type of questions asked in any monitoring or remote sensing research. For example to answer the question "what is the estimated vegetated cover in a 24,000 acre preserve before a fire and five years after the fire?", Landsat should be used. However, to answer the question of "whether the preserve is type converting because of the fire?", would require ADAR or a similar system. A more comprehensive comparison is offered in table 5.2.

Table 5.2 Landsat - ADAR Resolution Assessment Potential Comparison

Targets Well Resolved	Landsat	ADAR*
Bare soil	Yes	Yes
Vegetation	Yes	Yes
Individual Plants (Trees-Shrubs)	No	Yes
Vegetation Community Classification	Limited	Yes
Cars	No	Yes
Streets	No	Yes
Freeways	Yes	Yes
Individual Houses	Limited	Yes
Building	Yes	Yes
Grading	Yes	Yes
Off-Road Activity	Very Limited	Yes
Trails	No	Yes
Fire Scars	Yes	Yes
Phenological change	Limited	Yes
Successional Changes	Limited	Yes

* Costs considered exorbitant for areas greater than 3000 acres

VI. Conclusion

The primary benefits of Landsat are its relatively inexpensive acquisition cost and its ease of application due to the level of preprocessing that has been done prior to purchase. Although the pixel size of the Landsat imagery limits its use with very small ground features, it performs very well on landscape scales resolving larger features, i.e., fires, grading, large extent vegetation change, impermeable surfaces, landslides, natural disasters, etc. (features >30 m^2). Landsat imagery is considered a "commercial-off-the-shelf" (COTS) product in the remote sensing community. This imagery can be used in an initial assessment of potential land cover and vegetation change over large areas requiring relatively little time and low cost. The change detection results can then be used to determine areas requiring field assessment or areas requiring higher resolution aerial photography such as 1 meter ADAR or lower resolution satellite imagery such as 5 meter IKONOS for more spatially extensive change detection applications. These technologies have potential practical applications for land use agencies in areas that have significant natural and human generated disturbances, e.g., fire and off-road activity, and could prove invaluable to conservation programs responsible for large open space areas. The

County of San Diego intends to further explore the use of these technologies in its land use analyses and MSCP monitoring program.

Acknowledgements

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Endnotes

1.) *Radiometric registration* or normalization, sometimes confused with Radiometric resolution, refers to the process that matches the radiance values of two or more images by means of a linear transformation (Hall et al. 1991).

2.) The 10-15% change mask figure reflects an iterative process of experimentation where the desired results were an improved signal to noise ratio between actual change and false change. Although the percent figure could have been set at a lower threshold of change detection, we consider it scientifically unsound. Expected natural year to year variability of vegetation physiogamy (or possibly due to minor pixel to pixel registration errors), ecologically insignificant or nonexistent amounts of change (noise) will still be recorded as "change". Subsequently, the resulting change mask would introduce more error than it would detect in actual change.

References

Hall, F.G., Strebel, D.E., Nickeson, J.E., Goetz, S.J. 1991.
Radiometric rectification: Toward a common radiometric response among multi-date, multi-sensor images. Remote Sensing of the Environment. 35:11-27.

Jensen, J.R., 1996. Introductory Digital Image Processing.
Simon&Schuster Upper Sadle River, New Jersey

Lambin, E.F.; A.H. Strahler. 1994. Indicators of land-cover change for change-vector analysis in multitemporal space at coarse spatial scales. International Journal of Remote Sensing. 15(10): 2099 - 2119.

LOGICON, 1997 Multispectral Imagery Reference Guide. LOGICON Geodynamics, Inc. Spectral Imagery Training Center. Fairfax, Virginia.

MSCP Habitat Monitoring: Remote Sensing at San Diego State University.
HTTP://Map.SDSU.EDU/GROUP2001/GROUP7/INDEX.HTM

Schott, J.R., Salvaggio, C., and Volchok, W.J. 1988. Radiometric
Scene normalization using pseudoinvariant features. Remote Sensing of the Environment. 26:1-16.

Singh, A. 1989. Digital change detection techniques using remotely-sensed data. International Journal of Remote Sensing. 10(6): 989-1003.

Townshend, J.R.G., C.O. Justice, C. Gurney, J. McManus. 1992. The
Impact of misregistration on change detection. IEEE Transactions on Geoscience and Remote Sensing. 30(5):1054-1060.

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Appendix 3

Glossary of Terms†

Airborne Data Acquisition and Registration (ADAR) – The ADAR System 5550, developed by Positive System acquires high resolution (0.5 to 3 meter GRE) multispectral digital photographs using an airplane platform.

Band – A portion of the electromagnetic spectrum, a range of wavelengths. A spectral band, in the context of remote sensing, is a discrete region of the spectrum resolved by a sensing element within the sensor's imaging array.

Binary change mask[1] – Created by using the output image of a change detection function. A threshold value of change is selected to identify areas of change and no-change in the new image. The change image is then recoded to a value of one for change or a value of zero for no-change.

Change detection – Process by which two images are compared pixel by pixel, and an output is generated whenever corresponding pixels have sufficiently different gray values.

Change detection images – Images prepared by digitally comparing two original images acquired at different times. The gray tones of each pixel on a change detection image portray the amount of difference between the original images.

Color composite (multiband photography) – A color image produced by assigning colors to particular spectral bands. In Landsat TM, for example, assigning red to band 3 (0.63 to 0.69 um), green to band 2 (0.52 to 0.6 um) and blue to band 1 (0.45 to 0.52 um) results in a true color composite, approximating what human vision normally perceives.

Electromagnetic spectrum – The ordered set of wavelengths of electromagnetic radiation extending from short-wavelength cosmic waves to long-wavelength radio waves.

Geographic Information Systems (GIS) – An information system that is able to encode, store, transform, analyze, and display geospatial information.

Gray scale – Range of gray values from black to white.

Ground Resolution Element (GRE) – *See spatial resolution.*

Histogram[1] – A graphic representation of the information content of a remotely sensed image.

Image – Spatial representation of an object, a scene, or a map, that may be abstractly represented by a continuous function of two variables defined on some bounded region on a plane. An ordered two dimensional array of pixels.

Image differencing – The simple identification of the amount of change between two images by subtracting one band of one date from that of a different date. The images must first have been rectified to a common base map.

Image enhancement – Any one group of operations that improve the visual detectability of targets or categories. These operations include contrast improvement, image smoothing, histogram matching and noise suppression.

Image interpretation – The art and science of examining photographic images for the purpose of identifying objects and judging their significance.

Image processing – All operations that can be applied to image data, including preprocessing, enhancement, quantification, and classification.

Image registration – Alignment process by which two images of the same scene are positioned coincident with respect to each so that corresponding elements of the same ground area appear in the same position on the registered image.

Infrared – Pertaining to energy in the 0.7 - .11um wavelength region of the electromagnetic spectrum. For remote sensing, the infrared wavelengths are often subdivided into near infrared (0.7 – 1.1um), shortwave infrared (1.1 – 3um), midwave infrared (3 – 5um), and longwave infrared (5 – 15um).

Landsat – Unmanned, sun-synchrounous orbiting, U.S. earth resources satellite operated by Space Imaging EOSAT.

Map – A graphical representation in a plane surface, at an established scale, of the physical features (natural, artificial, or both) of a part of the earth's surface.

Multispectral Imagery – Images obtained simultaneously in a number of discrete bands in the electromagnetic spectrum.

Near infrared (NIR) – The preferred term for the shorter wavelengths in the infrared region extending from about 0.7um (visible red) to around 1.1um (the definition varies substantially by application and researcher). The longer wavelengths end grade into the shortwave infrared. The term really emphasizes the adiation reflected from plant materials, which peaks around 0.85um. It is also called solar infrared, since most of the IR energy from the sun lies in this spectral region.

Normalized difference vegetation index (NDVI)[1] – A measurement of vegetative amount and condition based on analysis of remote sensing spectral measurements. This techniques involves band ratioing where NDVI = (NIR) – Visible)/(NIR + Visible).

Orbit – The path of a satellite around a body determined by the law of gravity.

Orthorectification – The process of the photogrammetric adjustment of a satellite image to remove geometric distortions caused by the imaging sensor and terrain relief displacement.

Pixel – A picture element having both spatial and spectral properties. The spatial variable defines the apparent size of the resolution cell (i.e., the area on the ground represented by the data values), and the spectral variable defines the intensity of the spectral response for that cell in a particular band.

Preprocessing – Operation applied before image analysis is performed that can remove noise from, register, and enhance images.

Radiometric resolution – The minimum measured differences in signal strength.

Remote sensing – Techniques used to gather and process information about an object without direct physical contact.

Resolution – The measure of the ability of an optical system to distinguish between signals that are spatially near or spectrally similar.

Satellite – An object in orbit around a celestial body.

Scene – In a passive remote sensing system, everything occurring spatially or temporally before the sensor, including Earth's surface, the energy source, and the atmosphere, that the light energy passes though as it travels from its source to the Earth and from the Earth to the sensor.

Sensor – Any device that gathers energy or electromagnetic radiation, converts it into an electronic signal, and presents it in a form suitable for obtaining information about the environment.

Spatial resolution – The ability of an entire remote sensor system to rendor a sharply defined image. Also, a measure of the smallest angular or linear separation between two objects that can be resolved by the sensor.

Spectral bands – An interval in the electromagnetic spectrum defined by the two bounding wavelengths, frequencies, or wavelengths.

Spectral resolution – (1) The width of specific wavelength intervals in the electromagnetic spectrum to which a sensor is sensitive; (2) A sensor's imaging capabilities in terms of the spectral bandwidths, the number of spectral bands, and the location of those bands on the electromagnetic spectrum.

Tasseled Cap Transformation[2] – Rotates the MSS data such that the majority of information is contained in three components or features that are directly related to physical scene characteristics (brightness, greenness, and wetness). Brightness refers to the principal variation in soil reflectance; greenness is strongly related to the amount of green vegetation present in a scene; wetness relates to canopy and soil moisture.

Temporal resolution – Time interval between imaging collections over the same geographic location.

Thematic Mapper (TM) – A 7-bad multispectral sensor carried aboard Landsats –4, 5, 6 and 7. The bands are in the visible (bands 1, 2, 3); near infrared (band 4); shortwave0infrared (bands 5 and 7); and thermal infrared (band 6) regions. The spatial resolution is 28.5 meters for bands 1 through 5 and 7, and 120m for band 6 (60m for Landsat-7).

Wavelength – Distance between successive wave crest or other equivalent points in a harmonic wave.

Write function memory insertion[1] – The insertion of bands of remotely sensed data into specific write function memory banks (red, green, and-or blue) in the digital image processing system to visually identify change in the imagery.

†*All glossary terms taken from the following:*

LOGICON, 1997. Multispectral Imagery Reference Guide. LOGICON Geodynamics, Inc. Spectral Imagery Training Center. Faifax, Virginia.

Except:

[1]**Jensen, J.R**., 1996. Introductory Digital Image Processing. Simon and Schuster. Upper Sadle River, New Jersey.

[2]**Lillesand, T.M. and R. W. Kiefer, 1994**. Remote Sensing and Image Interpretation. 3rd Edition. John Wiley and Sons, Inc. New York, New York.